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SPACE SHUTTLE AFRSI OMS PODS/JOINTS DEVELOPMENT TEST USING MODEL 116-Ø SPECIMENS AND MODEL 96-Ø TEST FIXTURE IN THE AMES RESEARCH CENTER 11x11-FOOT TRANSONIC WIND TUNNEL (OS304A)

by

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Prepared under NASA Contract Number NAS9-16283

by

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for

Engineering Analysis Division

Johnson Space Center
National Aeronautics and Space Administration
Houston, Texas

WIND TUNNEL TEST SPECIFICS:

Test Number:	ARC 11TWT 501-1
NASA Series Number:	OS304A
Model Number:	116-Ø/96-Ø
Test Dates:	2 June 1981 to 8 June 1981
Occupancy Hours:	75

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ABSTRACT

An experimental investigation (OS304A) was conducted in the NASA/Ames Research Center 11-Foot Transonic Wind Tunnel from June 2, 1981 through June 8, 1981. The purpose of the test was to subject Advanced Flexible Reusable Surface Insulation (AFRSI) specimens to an environment simulating the flow characteristics encountered at the OMS pods of the Space Shuttle vehicle during ascent, and to evaluate the AFRSI joints in this environment.

Two pairs of AFRSI specimens, one pair with a light fabric cover and the other with a heavier covering, were subjected to the same two tests: a calibration test and a life test in an expansion/recompression shock environment. Of each pair, one test pad was instrumented for calibration purposes.

The heavy fabric specimen completed the life test successfully. The light-surfaced life test article failed early, but its instrumented counterpart suffered no damage in the "failure area" during 110 minutes exposure to dynamic pressures above 400 psf.

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INTRODUCTION

Advanced Flexible Reusable Surface Insulation (AFRSI) is presently under consideration as a potential replacement for the Low-Temperature Reusable Surface Insulation (LRSI) tiles on the Space Shuttle. The AFRSI is a quilted blanket consisting of silica fiber felt insulation material with a quartz fabric OML cover and a glass fabric IML lining. The quilting is done with quartz thread stitched through the three layers of material. The blanket IML is bonded to the skin of the vehicle while the OML face is exposed to the high-pressure gradients, fluctuating acoustic pressures, and wind shear stresses attendant to atmospheric flight. The blankets are pliable, but individual fibrous elements are hard and brittle, and susceptible to damage, especially where they cross each other. Therefore, the durability of various AFRSI configurations in the presence of pressure gradients and turbulent airflows requires investigation.

The purpose of the test was to subject AFRSI specimens to an environment simulating the shock, pressure gradients, and turbulence characteristics encountered at the orbiter OMS pods during ascent. A second objective was to evaluate AFRSI joints in this environment.

The test was conducted in the NASA/ARC 11x11-foot transonic wind tunnel from June 2 through June 8, 1981. Twelve runs were completed during 75 hours of occupancy.

The test articles consisted of two pairs of AFRSI specimens, one with a light fabric cover and the other with a heavier covering, all configured to the same pattern. Of each pair, one test pad was instrumented for calibration purposes while the other pad was subjected to a life test.

An expansion/recompression shock environment was generated by deflecting the leading edge flap on the test fixture in order to create pre-determined pressure disturbances in the recompression region on the specimens. The calibration test consisted of Mach number sweeps (0.76 to 0.88) for each of three or four dynamic pressures in the 350 to 700 psf range. Static pressures on the surface and subsurface of the specimens were measured as well as fluctuating acoustic pressures inside the insulation material. For the life test, the same Mach sweep was made at a constant dynamic pressure of 700 psf for a total cumulative time of 200 minutes, equivalent to 400 missions unless failure occurred prior to that time.

This investigation was the first of a two-phase development test program where the second phase (OS304.B) was conducted in the ARC 9x7-foot supersonic wind tunnel and was reported separately (DMS-DR-2502).

This report presents information on the conduct of the test; descriptions of the test fixture, of the specimens, and of the test facility; instrumentation particulars; and a sample of the pressure data collected during the test. Pre-test and post-test pictures of the specimens are included.

NOMENCLATURE

SYMBOL	MNEMONIC	DEFINITION
C_p	CP	Pressure coefficient
D_B	DB	Decibel representation of P_{RMS}
M	MACH	Freestream Mach number
P_∞	P	Freestream static pressure, psia
P_ℓ	PL	Local static pressure, psia
P_{RMS}	PRMS	RMS value of the variations from the mean value of the local pressure, psi
P_t	PT	Freestream total pressure, psia
q	Q	Freestream dynamic pressure, psf
R_e	RE	Freestream Reynolds number, per ft
T_s	TS	Freesteam static temperature, ^oR
T_t	TT	Freestream total temperature, ^oR
V_∞	VEL	Freestream velocity, ft/sec
X	X	Longitudinal distance positive, inches aft of round insert at flap trailing edge
Y	Y	Lateral distance positive, inchdes right of fixture centerline
δ_F	DFLAP	Test fixture flap setting, degrees
ρ	RHO	Freestream density, slugs/ft^3

Other symbology includes,

AFRSI	Advanced Flexible Reusable Surface Insulation
LRSI	Low-Temperature Reusable Surface Insulation
IML	Inner Mold Line
OML	Outer Mold Line
OMS	Orbiter Maneuvering Subsystem

NOMENCLATURE (Concluded)

RTV	Room Temperature Vulcanizing (bonding material)
TOC	Time on Condition
VHT	Very High Temperature (silicon spray)

Specimen identification symbols:

1	11-foot wind tunnel
C	Calibration
T	Test (life)
L	Light cover
H	Heavy cover

REMARKS

During calibration run 12 (test pad 1CL), the Newport digital voltmeter readout indicated a possible malfunction of the zero (port 0) on scanivalve No. 2. The rotor and stator were replaced and the scanivalve was checked out. However, prior to the next calibration run, drifting was again observed on the same first zero. Testing was resumed using the second zero on port 11. All data acquired after run 11 should be referred to that second zero.

Kulite No. 601 on the 1CH test pad was replaced prior to run 31 because of noise problems.

All test objectives were met. The heavy fabric specimen (1TH) completed the life test successfully. Some superficial damage to the surface fabric was observed during the initial portion (Mach 0.76) of the test. No insulation (Q-felt) material was lost and the test was completed without any further deterioration of the AFRSI.

Test pad 1CL suffered some minor damage during calibration run 8 at q = 420 psf. VHT silicone spray was applied to the damaged area to stiffen the surface fibers and testing at the higher q's was resumed. Final inspection, after completion of the test, showed very little additional damage to the specimen.

Specimen 1TL failed after 16 minutes of its life-test run. The anomaly here was that the failure originated near the specimen leading edge at coordinates X=3.5 and Y=-3.5, and although the fabrication of test pads 1CL and 1TL was supposed to be identical, the former suffered no damage whatsoever in that particular area during 110 minutes of exposure at q > 400 psf.

Pre-test and post-test pictures of the four specimens tested are shown in Figures 8a through 8g.

No appreciable difference was detected between the surface and subsurface static pressure measurements on either calibration specimen.

CONFIGURATIONS INVESTIGATED

Model Description

Model 96-Ø (drawing SS-A01872, February 21, 1979 modification) was employed for this test. The fixture, depicted in Figure 1, consists of a flap mounted at the leading edge of a specimen holidng frame, two side plates and a sealed pressure box enclosing the space beneath the holding frame.

Deflection of the hydraulically actuated flap produced the desired expansion/recompression shock wave patterns in a two-dimensional environment. For flap angles $\geq$ 18 degrees, the freesteam transonic flow was accelerated on the forward ramp (flap) to sonic/supersonic speed near the top of the ramp where an expansion shock pattern was generated. For the larger flap deflections ($\geq$ 26 degrees), this acceleration created a high negative pressure gradient which resulted in the separation, or at least an incipient separation of the boundary layer downstream of the expansion shock system. Below 26 degrees, a similar pressure gradient occurred, but the flow remained attached to the boundary surface. As the high velocity stream lost energy, the transition from supersonic to subsonic flow yielded a recompression shock region with attendant positive pressure gradient and high turbulence levels (see Figure 2). For a given flap setting, the location and strength of the recompression shock pressure jump was determined by the freestream Mach number and dynamic pressure. In this test, the flap was deflected at 18 degrees while Mach number and dynamic pressure were adjusted to yield the required shock strengths and to locate the recompression shock region on the specimens.

A 4.5-inch spacer was used together with individual shims to bring the leading and trailing edges of the specimens flush with the surface of the fixture. A 0.725-inch shim was employed with the light fabric covered specimens, and a 0.595-inch shim with the heavy surfaced articles. These combinations were intended to compensate for the 6.5-inch depth of the supporting frame located in the pressure box.

Test Specimens

The AFRSI blankets consisted of silica fiber felt (Q-felt) insulation material with a silica cloth face covering and a glass cloth back lining, all quilted together with quartz thread in a one-inch-square grid pattern. The quilting was accomplished with a modified lock stitch. The outer covering or face sheet was made of either of two fabric weights: a "light cover" which was 0.010 inch thick (7 oz/sq.yard) or a 0.027 inch "heavy cover" (20 oz/sq.yard).

A total of four specimens were tested: two with light covers and two with the heavier face sheets. Of each pair, one specimen was instrumented to calibrate the flow at the surface and subsurface of the AFRSI material.

The test pads consisted of framed AFRSI panels (24x24 inches) bonded with RTV to 3/4-inch aluminum support plates (43.0x27.5 inches), so that the stitching loops were imbedded in the bonding material. One-inch-wide rectangular wooden frames surrounded the AFRSI material. The frame/specimen interfaces were closed off with aluminum retainer strips which covered the top surface of the frames and extended one inch over the blanket material,

leaving an exposed AFRSI surface of 20x20 inches. The retainer strip extensions were bonded to the top of the specimen material to prevent puffing and possible damage to the blankets. A diagonal AFRSI joint with a forward facing step approximately 1/4-inch high characterized all four test articles. Wooden blocks (16x24 inches) were butted against the trailing edge of the AFRSI panels to fill the unoccupied space on the support plates. The surface of these blocks was tapered toward the trailing edge to a thickness equal to that of the leading edge. A sketch of a test specimen assembly is shown in Figure 3.

The test pads were fabricated according to drawing SD-AFRSI-WTDT-1. The specimen identification nomenclature was as follows:

1CH: 11-foot TWT/Calibration/Heavy cover

1CL: 11-foot TWT/Calibration/Light cover

1TH: 11-foot TWT/Life Test/Heavy cover

1TL: 11-foot TWT/Life Test/Light cover

This group of four test pads together with the four that were tested in OS304B was designated model 116-0.

A picture of a specimen pad installed in the model 96-Ø test fixture is shown in Figure 7.

INSTRUMENTATION

The model test fixture and the two calibration specimens, 1CH and 1CL, were instrumented with static pressure taps and fluctuating pressure transducers. The general layout is shown in Figure 4, while the nominal and actual location coordinates of the instrumentation are listed in Tables I, IIa and IIb.

Static Pressure

The test fixture was instrumented with 14 static pressure taps: 12 on one side and two on the other. Each of the two calibration pads was instrumented with 30 surface taps and 10 subsurface taps, one of which (#409) was located on the diagonal joint.

Each surface pressure tap on a specimen consisted of a 0.042-inch OD steel tubing which came up through the support plate, extended through the insulation material, and was brazed to a brass flanged collar affixed to the cloth surface covering of the specimen. Beneath the support plate, each steel tube was attached to a piece of flex tubing contained in a small, separate pressure cup attached to the plate bottom. Sufficient flex tubing was available to permit motion of the surface material. In order to isolate the pressures on either side of the plate, the tubes exited from their individual pressure cups through sealed apertures.

The subsurface taps consisted of the same size steel tubing protruding approximately 1/8-inch above the support plate, into the lower strata of the AFRSI material. Details of the instrumentation installation are shown in Figure 5.

The actual location of the pressure taps was dictated to a large extent by the stitching alignment on the specimens. In many cases, the specified tolerance of ±0.5 inch from the nominal locations was unavoidably exceeded. On test pad 1CH, tap No. 306 was deleted because of the crowded condition in its proposed location.

Fluctuating Pressure

The test fixture was instrumented with six Kulite fluctuating pressure transducers aligned on the right side of the fixture. Each of the calibration pads was instrumented with three Kulite transducers. These were inserted in the support plates and protruded approximately 1/4 inch into the insulation felt material (see Figure 5).

TEST FACILITY DESCRIPTION

The NASA Ames 11-Foot Transonic Wind Tunnel is the transonic leg of the Ames Unitary facility. It is a closed-circuit, single-return, continuous-flow, variable-density tunnel. The 11 x 11 x 22-foot test section is slotted to permit transonic testing. The nozzle has adjustable sidewalls. The tunnel air is driven by a 3-stage axial flow compressor powered by 4 wound-rotor induction motors. The speed of the motors is varied as necessary to provide the desired Mach number. The motors have a combined output of 180,000 horsepower for continuous operation or 216,000 horsepower for one hour. Tunnel temperature is controlled by aftercoolers and a cooling tower. Four 30,000 cubic-foot storage tanks provide dry air for tunnel pressurization.

The tunnel can be operated at nominal Mach numbers of .5 to 1.4, Reynolds number per foot x 10^{-6} of 1.7 to 9.4, dynamic pressure (PSF) of 150 to 2,000 and a total temperature (^{o}R) of 540 to 610, respectively.

This tunnel is used for force and moment, pressure, internal air flow-inlet, and dynamic stability tests.

TEST PROCEDURE

The test conditions were divided into two general categories: calibration testing and life testing. All test runs in both categories were conducted with the fixture leading edge flap held constant at 18 degrees deflection.

Calibrations

For test pad 1CL, pressure data were obtained for Mach number sweeps ranging from 0.76 through 0.88 for each of four values of dynamic pressure: 350, 420, 550, and 700 psf.

The same Mach numbers, but only three dynamic pressures; 550, 700, and 420 psf, were used for test pad 1CH.

Life Tests

These tests were carried out at a constant dynamic pressure of 700 psf while Mach number was changed from 0.76 to 0.88 in seven increments of 0.02. Each specimen was to be subjected to the stipulated flow conditions for a cumulative time of 200 minutes, apportioned equally to each Mach number. Cumulative test time was measured from the point at which an initial q of 400 psf was reached. Testing was aborted if and when the specimen failed.

Testing of pad 1TH was conducted as planned with the tunnel condition being changed every 28.5 minutes. Pad 1TL failed after 16 minutes at Mach 0.76.

A summary of the runs completed including the test conditions and the time-on condition for each specimen is shown in Table III.

DATA REDUCTION

Standard tunnel equations were used to compute all tunnel conditions.

Local static pressure data were reduced to standard coefficient form,

$$C_p = (P_\ell - P_\infty) \times 144/q$$

RMS fluctuating pressure data were reduced to coefficient form and to DB form,

$$DB = 10 \log_{10} \left[\frac{P_{RMS} \times 10^9}{2.9007} \right]^2$$

These data were recorded continuously on magnetic tape and analyzed by Rockwell's Vibration and Acoustics unit (Dept. 380).

A typical data output printout is shown in Figures 6a through 6g.

REFERENCES

1. STS81-0447, "Pretest Information for the AFRSI OMS Pods/Joints Development Tests OS304A/B in the Ames Research Center (ARC) 11x11-Foot and 9x7-Foot Wind Tunnels Using Models 96-Ø and 81-Ø," June 1981.

TABLE I

INSTRUMENTATION LOCATION
MODEL 96-Ø FIXTURE

STATIC TAPS

Tap No.	X	Y
1	2.05	16.0
2	4.05	↓
3	6.05	
4	8.05	
5	10.05	
6	12.05	
7	14.05	
8	16.05	
9	18.05	
10	20.05	
11	24.05	
12	36.05	
13	4.05	-16.0
14	12.05	↑

FLUCTUATING PRESSURES
(KULITES)

Kulite No.	X	Y
K1	5	16
K2	9	↓
K3	11	
K4	13	
K5	15	
K6	19	

TABLE IIa

INSTRUMENTATION LOCATION

SPECIMEN 1CL

SURFACE

Tap No.	Nominal		Actual	
	X	Y	X	Y
101	1	6.0	0.95	6.25
102	3		2.95	
103	5		4.90	
104	6.5		6.50	6.30
105	7		7.15	5.95
107	9		9.10	6.00
109	11		11.10	
110	13		13.00	
111	15		15.00	
113	19		19.00	
301	1	0	0.95	0.30
302	3		2.95	0.30
303	5		4.90	0.35
305	7		6.85	0.40
306	8		7.35	0.40
307	9		9.40	0.50
308	9.5		10.35	0.25
309	11		11.10	0.05
310	13		13.00	
312	17		17.00	
313	19		19.00	
501	1	-6.0	0.95	-5.35
503	5		4.90	-5.60
505	7		6.95	-5.55
507	9		8.90	-5.50
509	11		10.85	-5.40
510	13		13.30	-5.70
511	15		15.00	-5.85
512	17		17.00	
513	19		19.00	

SUBSURFACE

Tap No.	Nominal		Actual	
	X	Y	X	Y
203	5	3.0	4.90	3.35
205	7		6.90	3.35
207	9		9.20	3.05
209	11		11.10	
210	13		13.05	
403	5	-3.0	4.90	-2.60
405	7		6.90	-2.60
407	9		8.85	-2.50
409	11		11.00	-2.35
410	13		13.00	-2.90

FLUCTUATING PRESSURES

Kulite No.	Nominal		Actual	
	X	Y	X	Y
K601	6	0.25	5.90	1.15
K602	8		7.85	1.25
K603	10		10.50	0.95

TABLE IIb

INSTRUMENTATION LOCATION

SPECIMEN 1CH

SURFACE

Tap No.	Nominal X	Nominal Y	Actual X	Actual Y
101	1	6.0	1.00	6.35
102	3		3.70	6.35
103	5		5.00	6.05
104	6.5		6.00	6.35
105	7		7.60	6.40
107	9		9.80	6.35
109	11		11.20	5.95
110	13		13.50	
111	15		15.70	
113	19		20.10	
301	1	0	1.00	0.75
302	3		3.40	0.75
303	5		5.65	0.65
305	7		7.90	0.65
306	8		-	-
307	9		8.65	1.05
308	9.5		10.30	1.05
309	11		11.65	0.65
310	13		13.85	
312	17		18.25	
313	19		20.55	0.55
501	1	-6.0	1.00	-5.55
503	5		5.15	-5.05
505	7		7.30	
507	9		9.60	
509	11		11.60	
510	13		13.45	-5.10
511	15		15.50	-5.15
512	17		17.75	-5.15
513	19		20.00	-5.25

SUBSURFACE

Tap No.	Nominal X	Nominal Y	Actual X	Actual Y
203	5	3.0	5.30	3.75
205	7		7.25	3.75
207	9		9.70	3.85
209	11		11.15	
210	13		13.45	
403	5	-3.0	5.20	-2.55
405	7		7.40	
407	9		9.85	
409	11		11.10	-2.40
410	13		13.15	-2.15

FLUCTUATING PRESSURES

FLUCTUATING PRESSURES

Kulite No.	Nominal X	Nominal Y	Actual X	Actual Y
K601	6	0.25	6.00	2.00
K602	8		8.20	1.85
K603	10		11.20	1.50

TABLE III RUN SUMMARY

AFRSI OMS PODS/JOINTS DEVELOPMENT TEST

11 x 11 ARC

TEST: OS-304A

DATE: 2 JUNE 1981

DATA SET IDENTIFIER	CONFIGURATION	δ_E	q	MACH NUMBER .76	.78	.80	.82	.84	.86	.88	TOC (MIN)	TEST RUN NUMBER
	1CL	18	350	7	—					→	53	
			420	8	—					→	43	
			550	10	—					→	38	
			700	12	—					→	29	
	1CH		550	31	—					→	26	
			700	33	—					→	24	
			420	34	—					→	18	
	1TH		700	14	16	18	19	20	22	23	200	
	1TL		700	24							16*	

TOC: TIME ON CONDITION
(for 1TH & 1TL, TIME @ q > 400 psf)
* FAILURE

1 7 13 19 25 31 37 43 49 55 61 67 75 76

COEFFICENTS

α OR β SCHEDULES

IDVAR(1) IF AS(2) IDV

NASA-MSFC-MAF

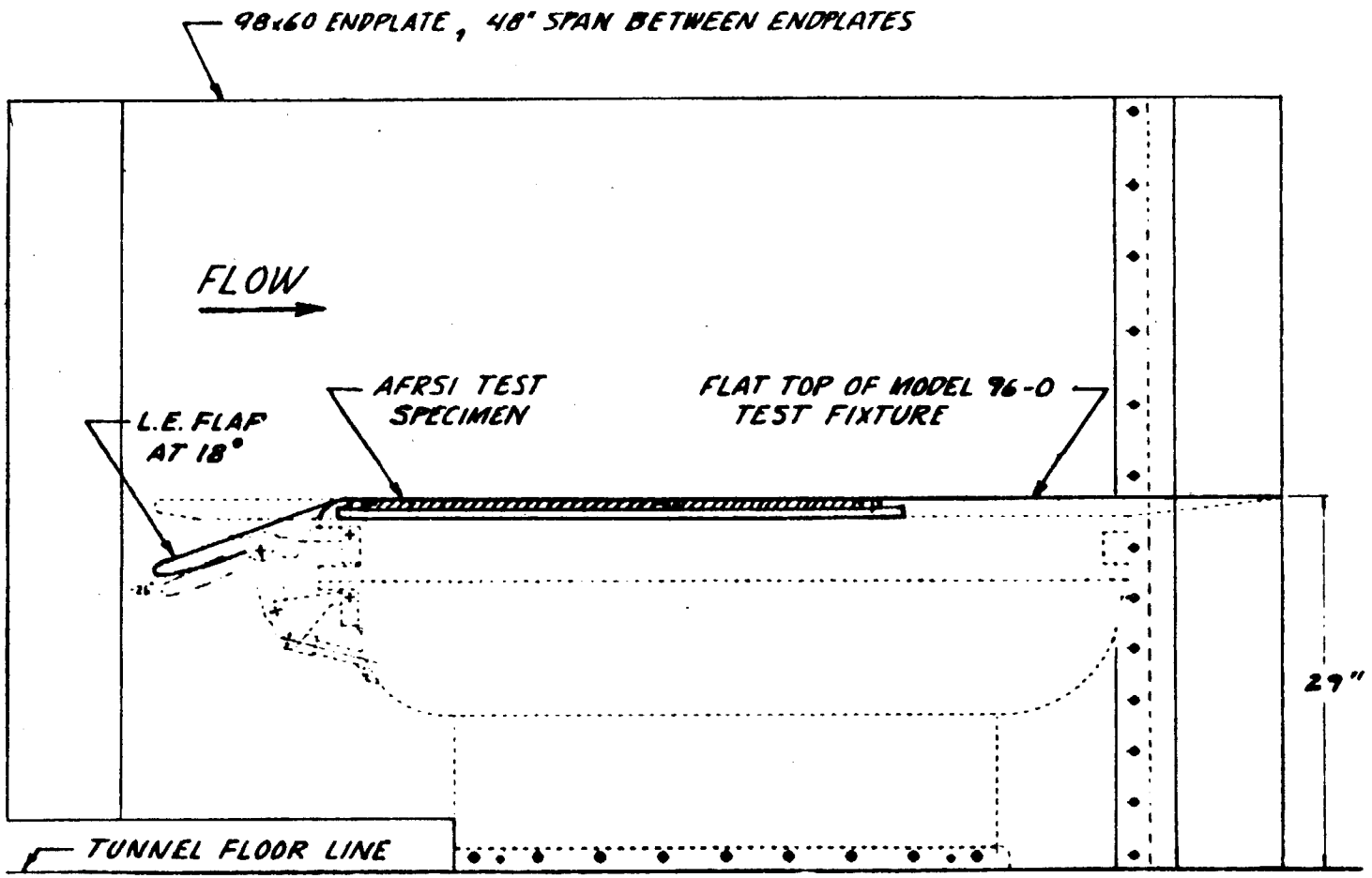


Figure 1. Model 96-Ø Test Fixture
General Arrangement

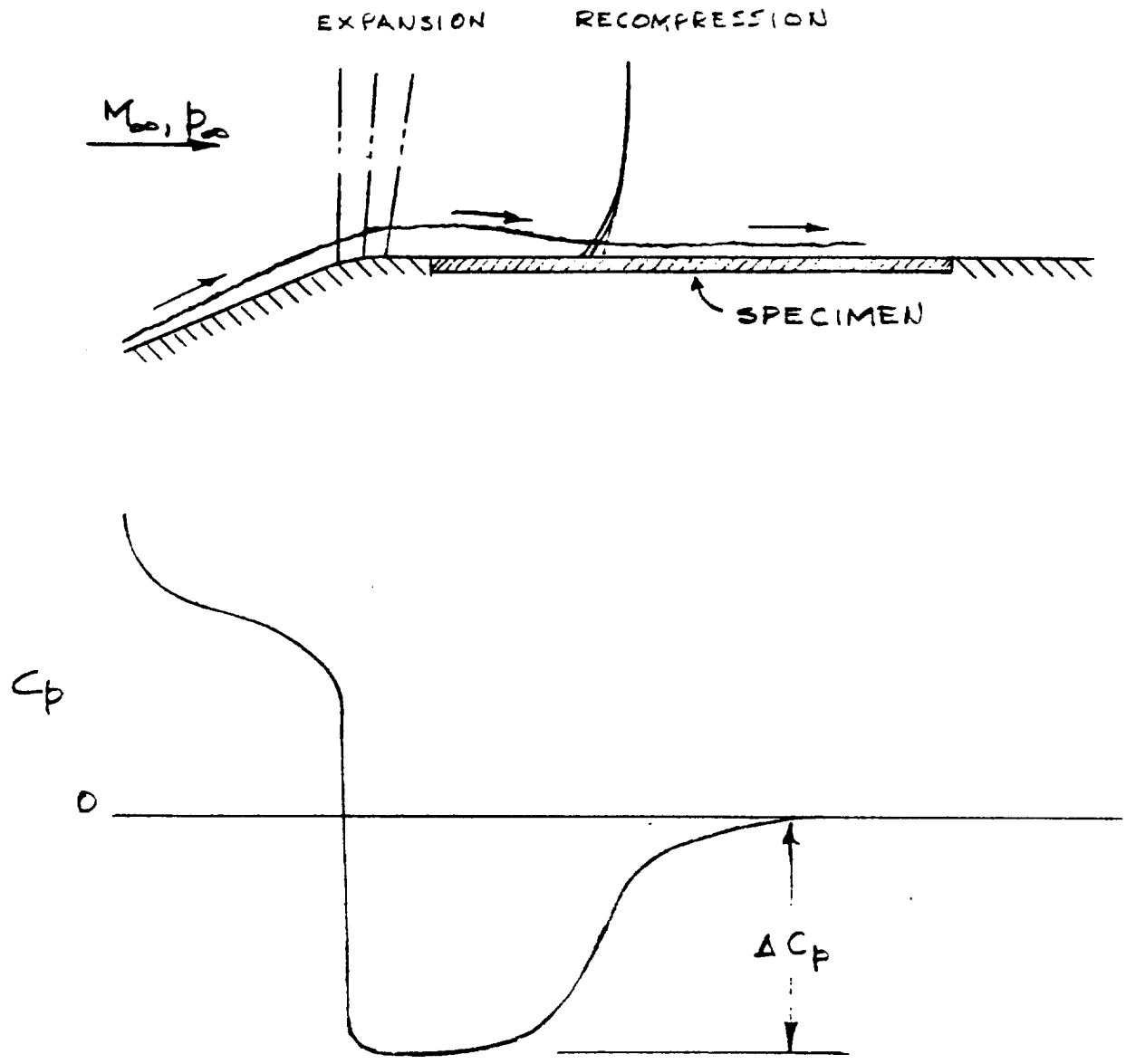


Figure 2
Typical Flow Field & Pressure Distribution
(Model 96-Ø)

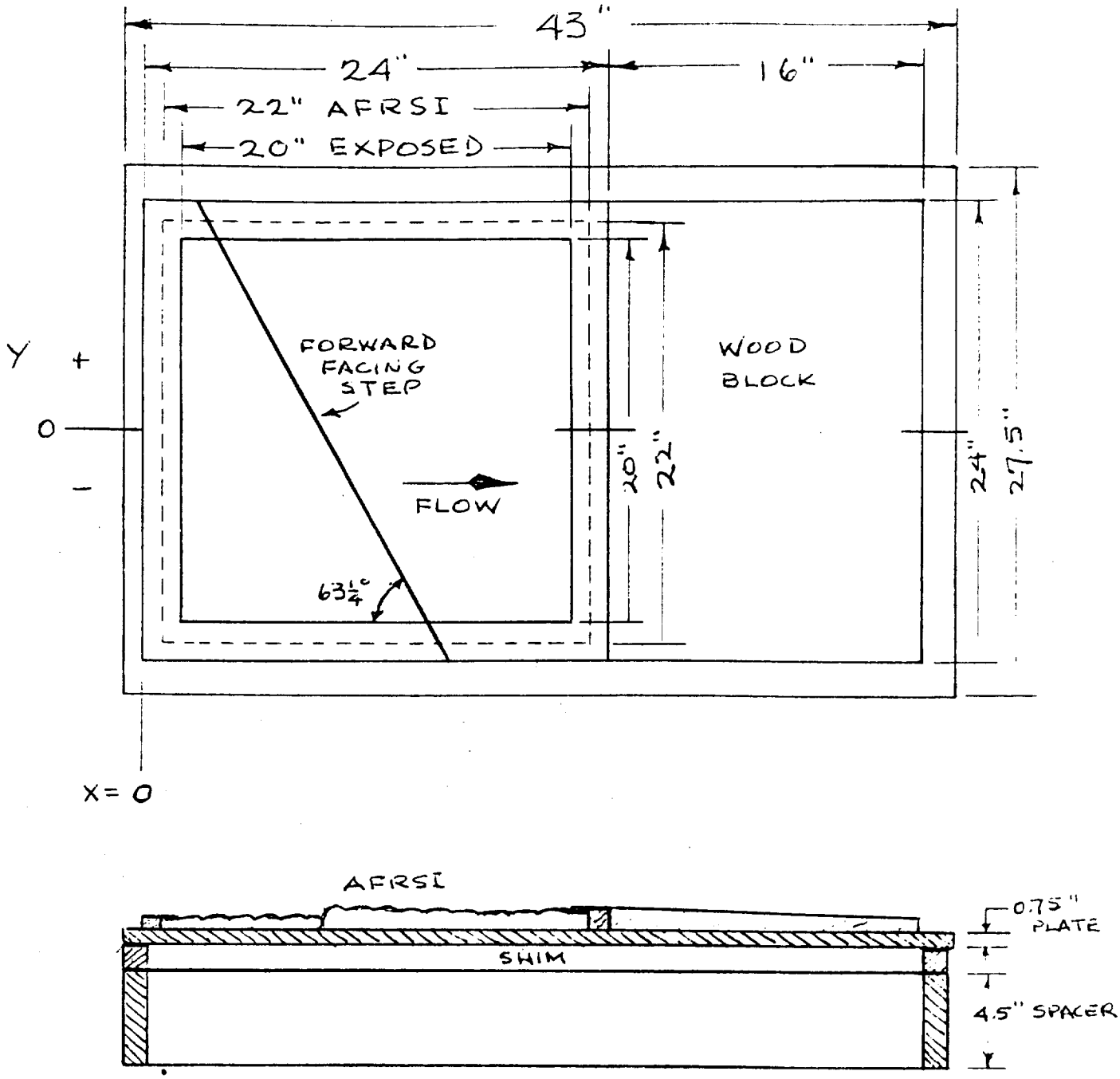


Figure 3
Model 116-Ø AFRSI Test Specimen Assembly

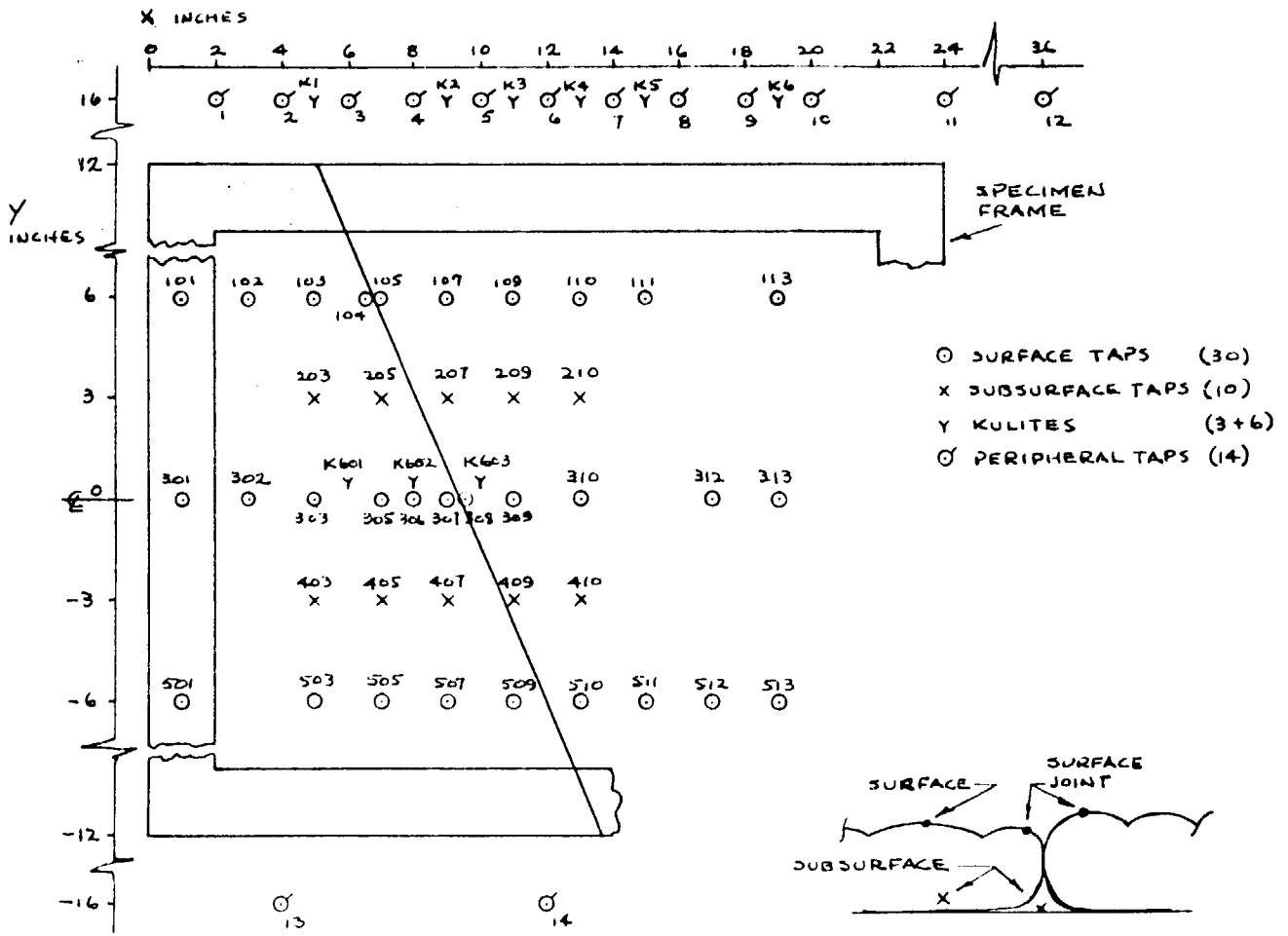


Figure 4
Specimen & Test Fixture Instrumentation

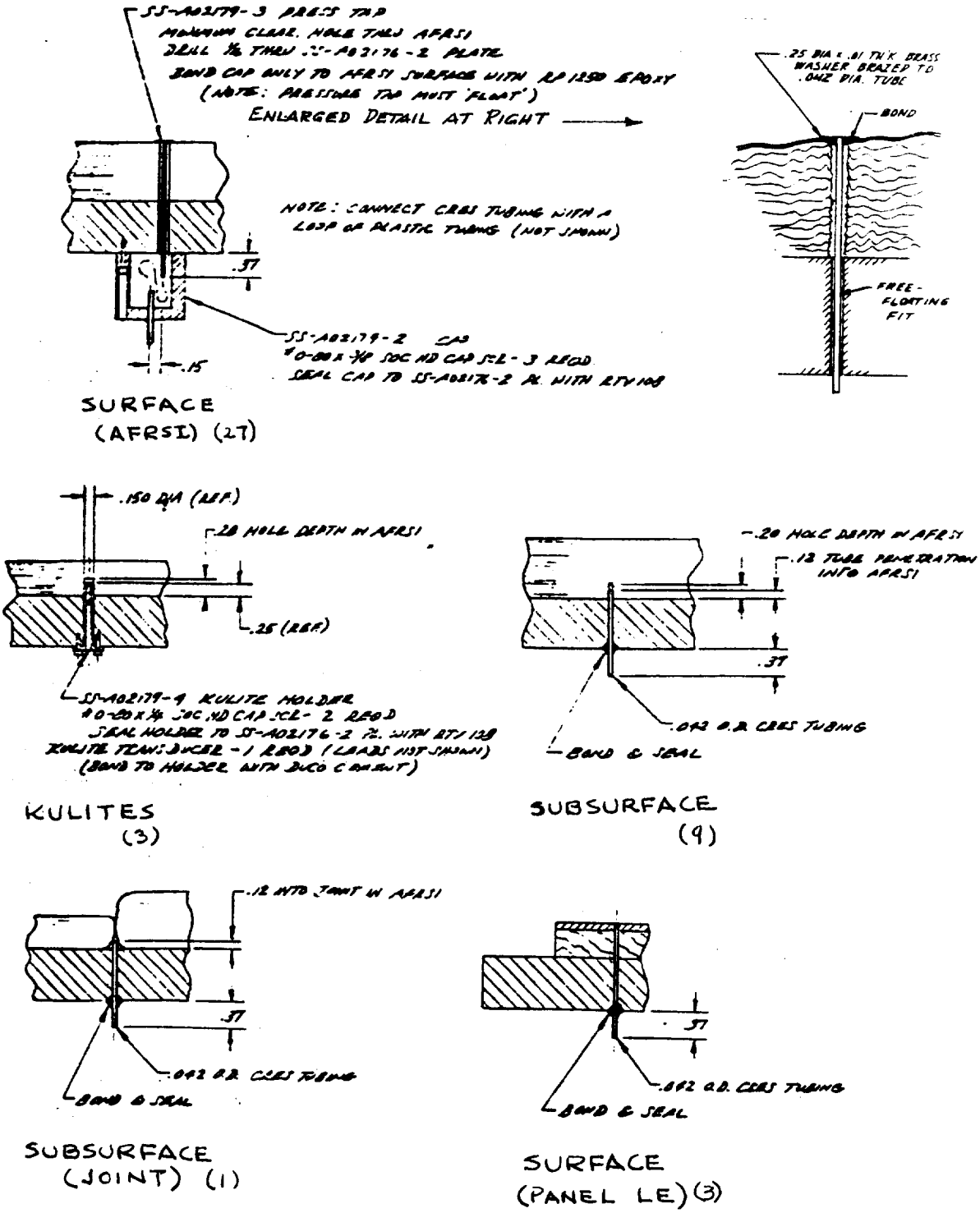

SS-A02179-3 PRESS TAP
MINIMUM CLEAR. HOLE THRU AFRSI
DRILL 1/8 THRU SS-A02176-2 PLATE
BOND CAP ONLY TO AFRSI SURFACE WITH RP 1250 EPOXY
(NOTE: PRESSURE TAP MUST 'FLOAT')
ENLARGED DETAIL AT RIGHT
NOTE: CONNECT CRES TUBING WITH A LOOP OF PLASTIC TUBING (NOT SHOWN)
.37
.15
SS-A02179-2 CAP
#0-80 X 1/8 SOC HD CAP SCR - 3 REQD
SEAL CAP TO SS-A02176-2 PL WITH RTV 108
SURFACE
(AFRSI) (27)
.25 DIA x .01 THK BRASS WASHER BRAZED TO .062 DIA. TUBE
BOND
FREE-FLOATING FIT
.150 DIA (REF.)
.28 HOLE DEPTH IN AFRSI
.25 (REF.)
SS-A02179-4 KULITE HOLDER
#0-80 X 1/8 SOC HD CAP SCR - 2 REQD
SEAL HOLDER TO SS-A02176-2 PL WITH RTV 108
KULITE TRANSDUCER - 1 REQD (LEADS NOT SHOWN)
(BOND TO HOLDER WITH DUCO CEMENT)
KULITES
(3)
.20 HOLE DEPTH IN AFRSI
.12 TUBE PENETRATION INTO AFRSI
.37
.042 O.D. CRES TUBING
BOND & SEAL
SUBSURFACE
(9)
.12 INTO JOINT IN AFRSI
.37
.042 O.D. CRES TUBING
BOND & SEAL
SUBSURFACE
(JOINT) (1)
.37
.042 O.D. CRES TUBING
BOND & SEAL
SURFACE
(PANEL LE) (3)

Figure 5
Instrumentation Details, Model 116-Ø Specimens

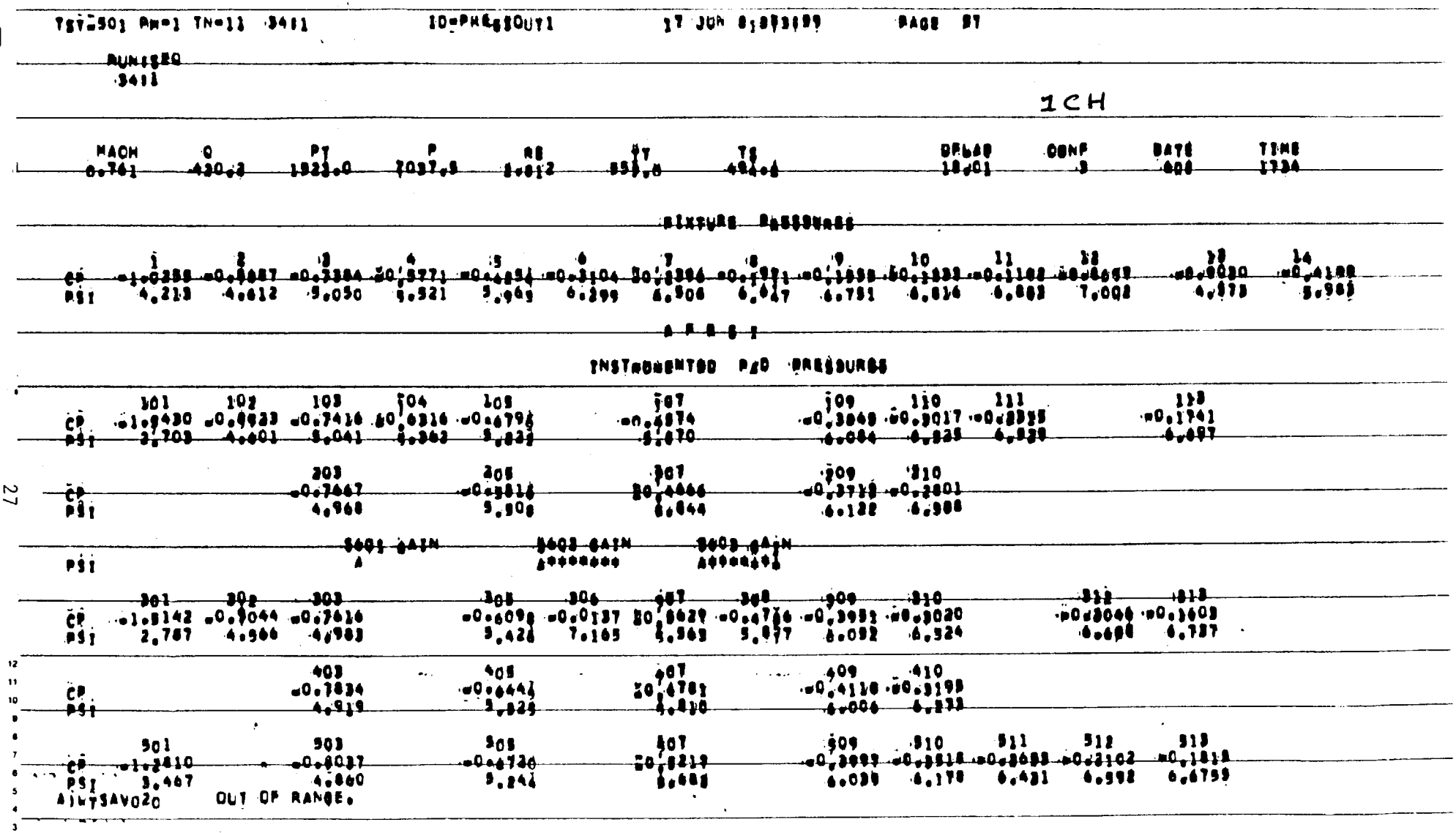


Figure 6a. Typical Data Output (OS304A).

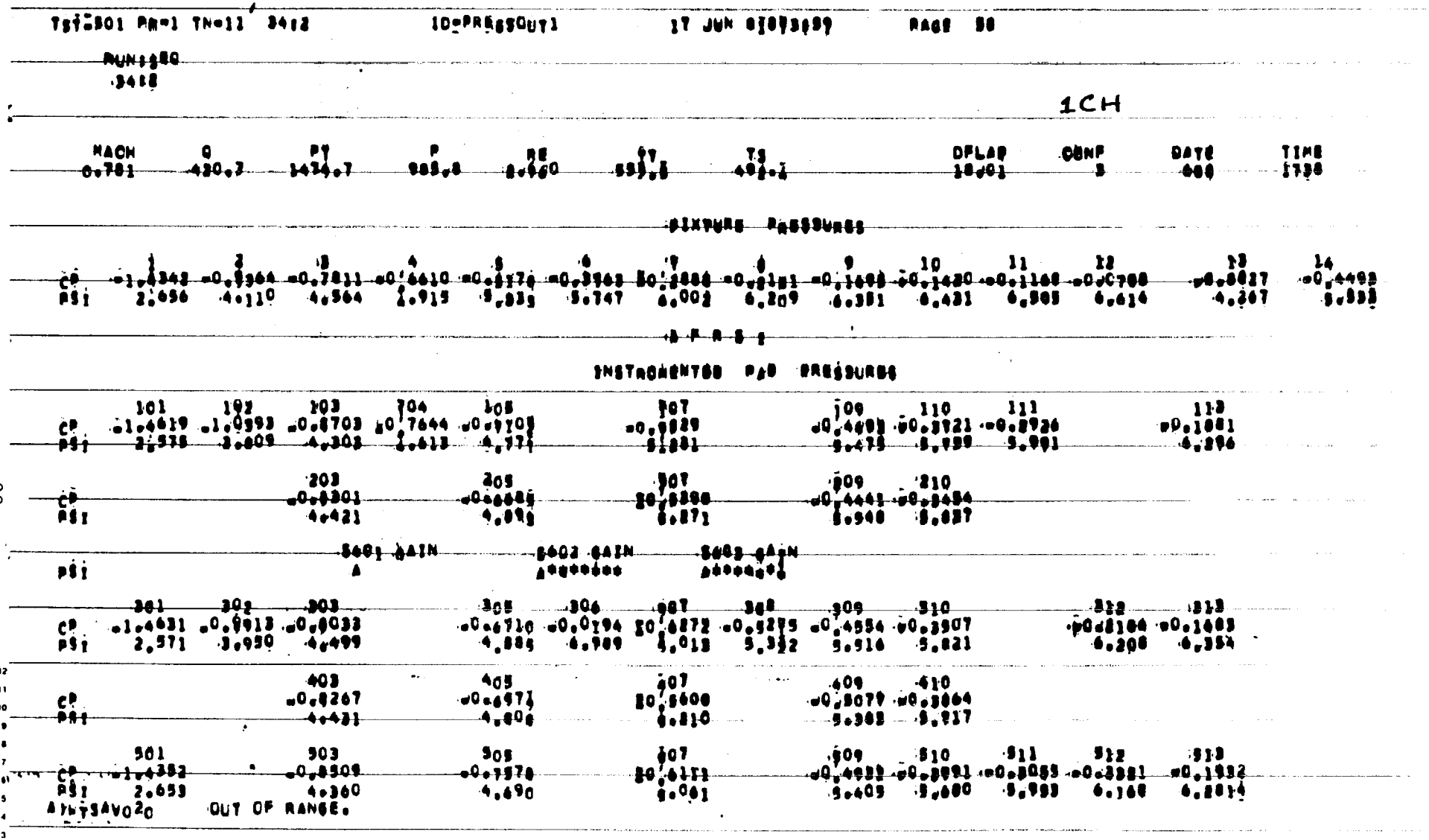


Figure 6b. Typical Data Output (OS304A)

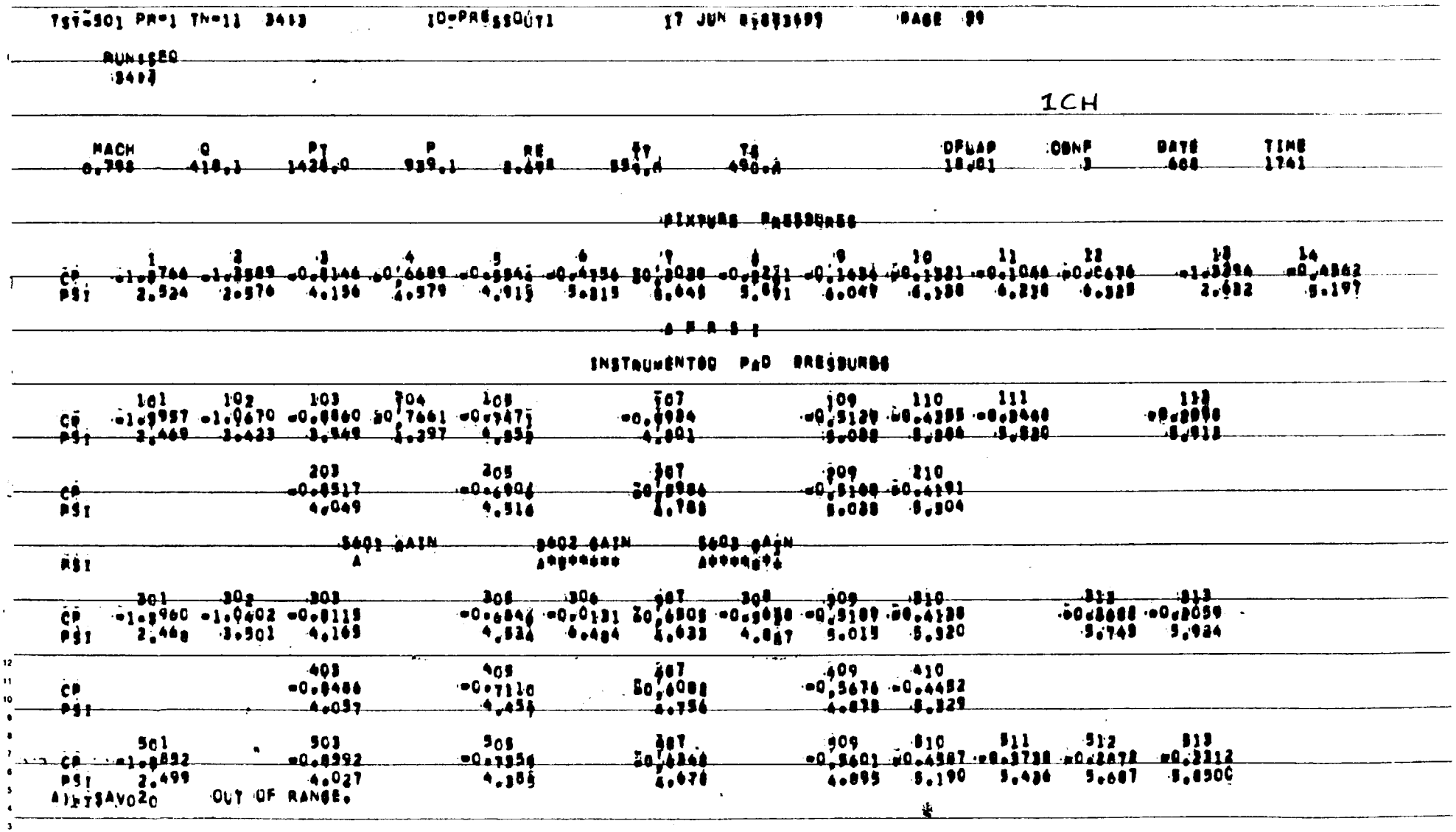


Figure 6c. Typical Data Output (OS304A)

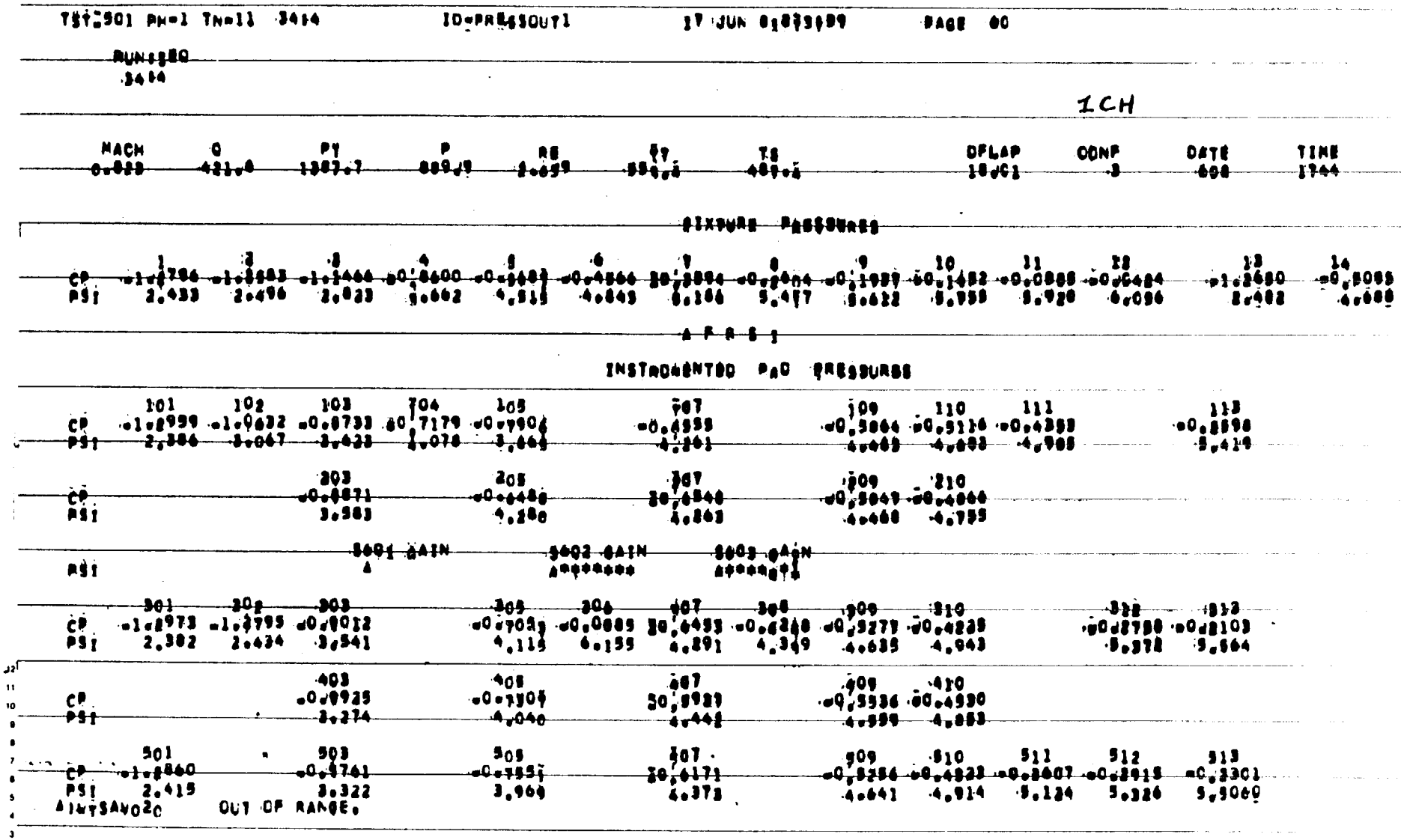


Figure 6d. Typical Data Output (OS304A)

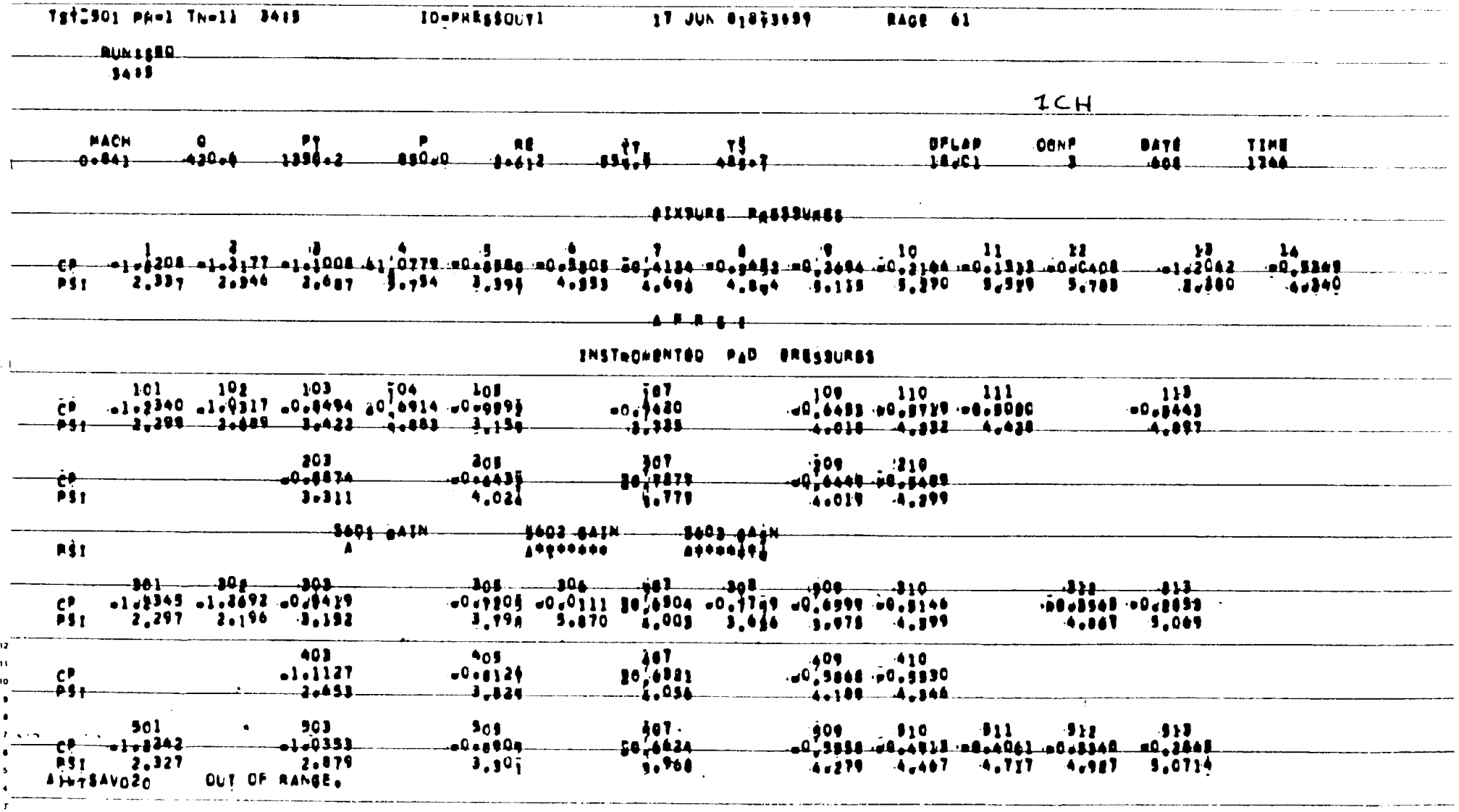


Figure 6e. Typical Data Output (OS304A)

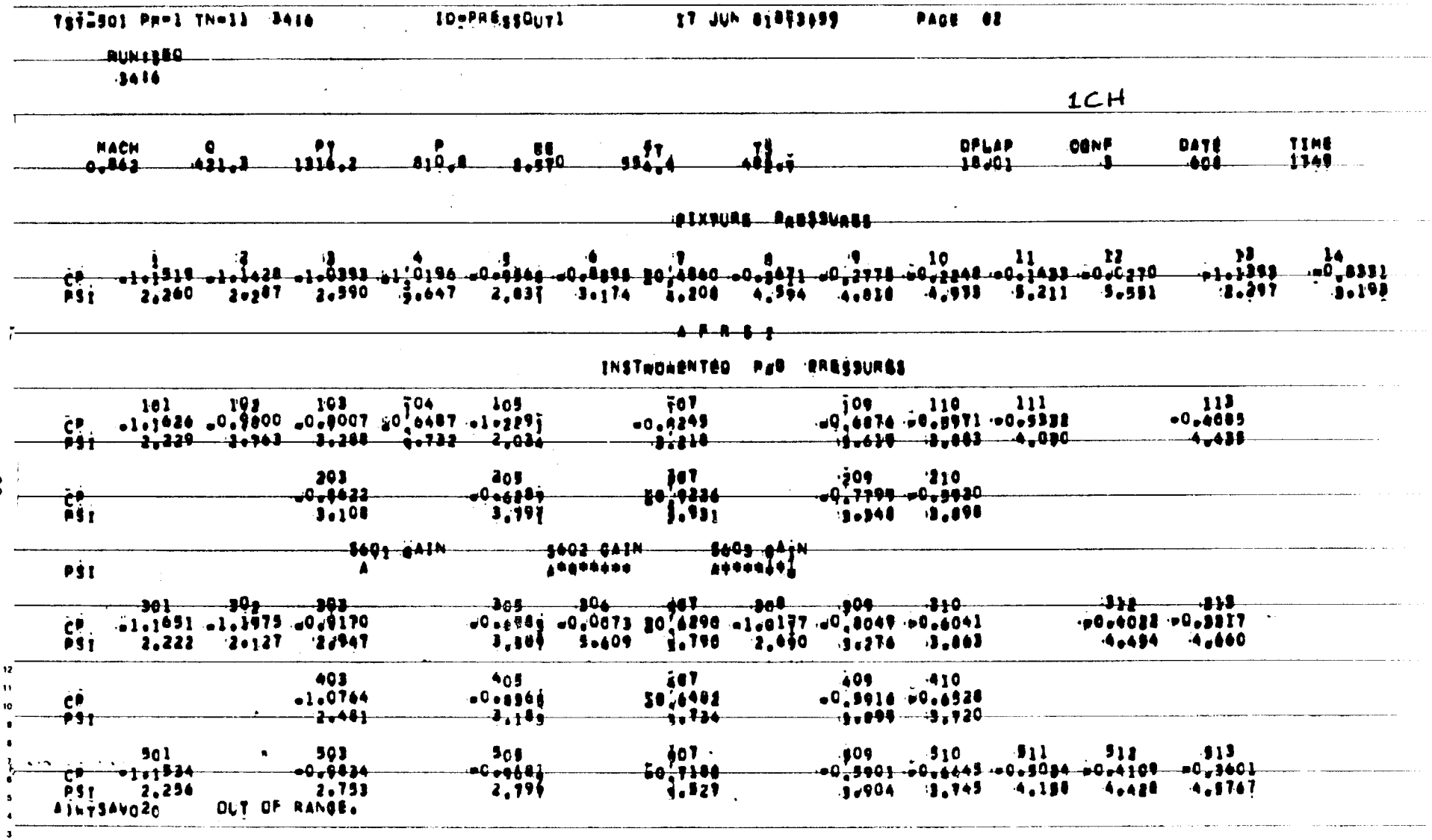


Figure 6f. Typical Data Output (OS304A)

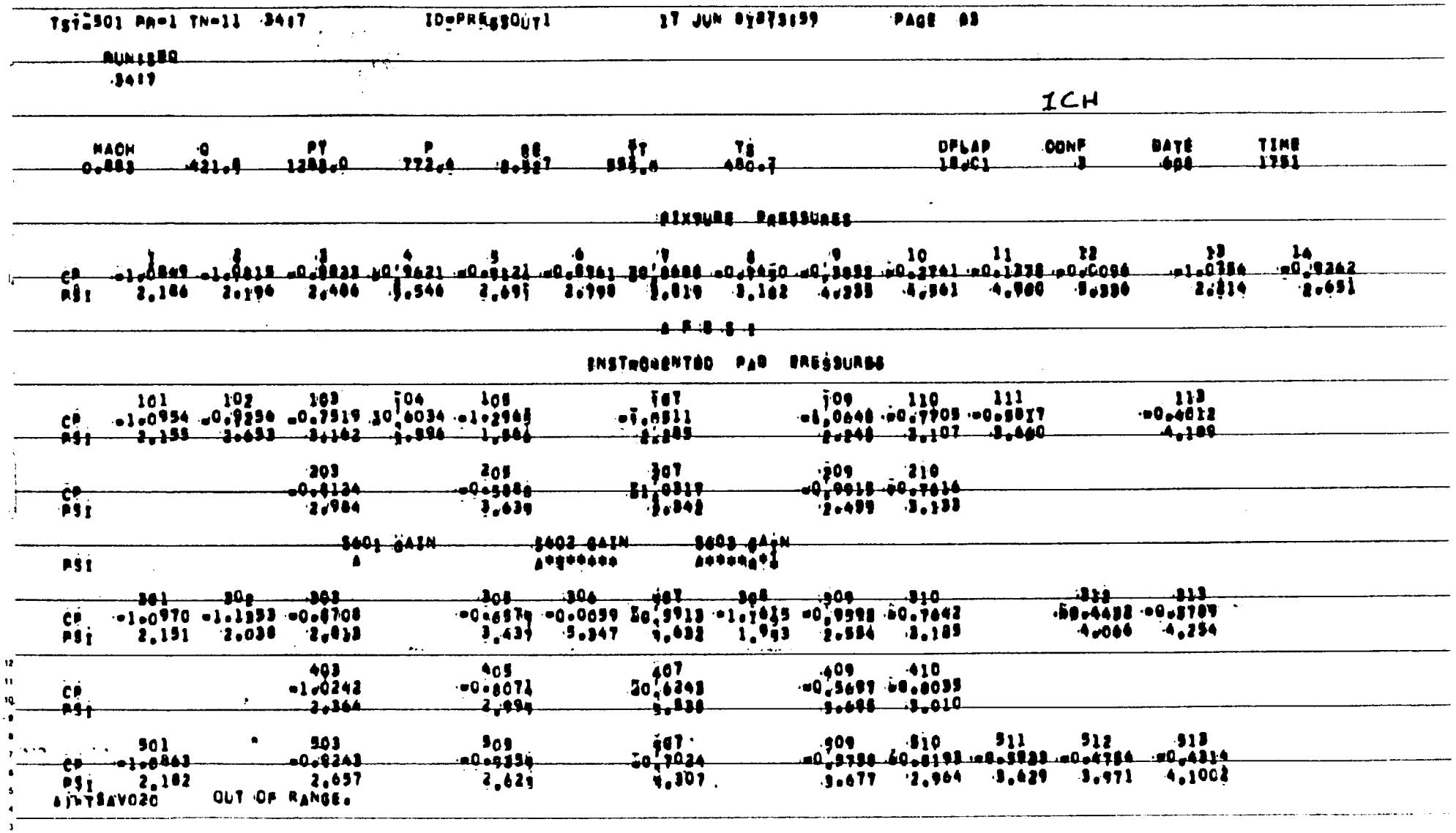


Figure 6g. Typical Data Output (OS304A)

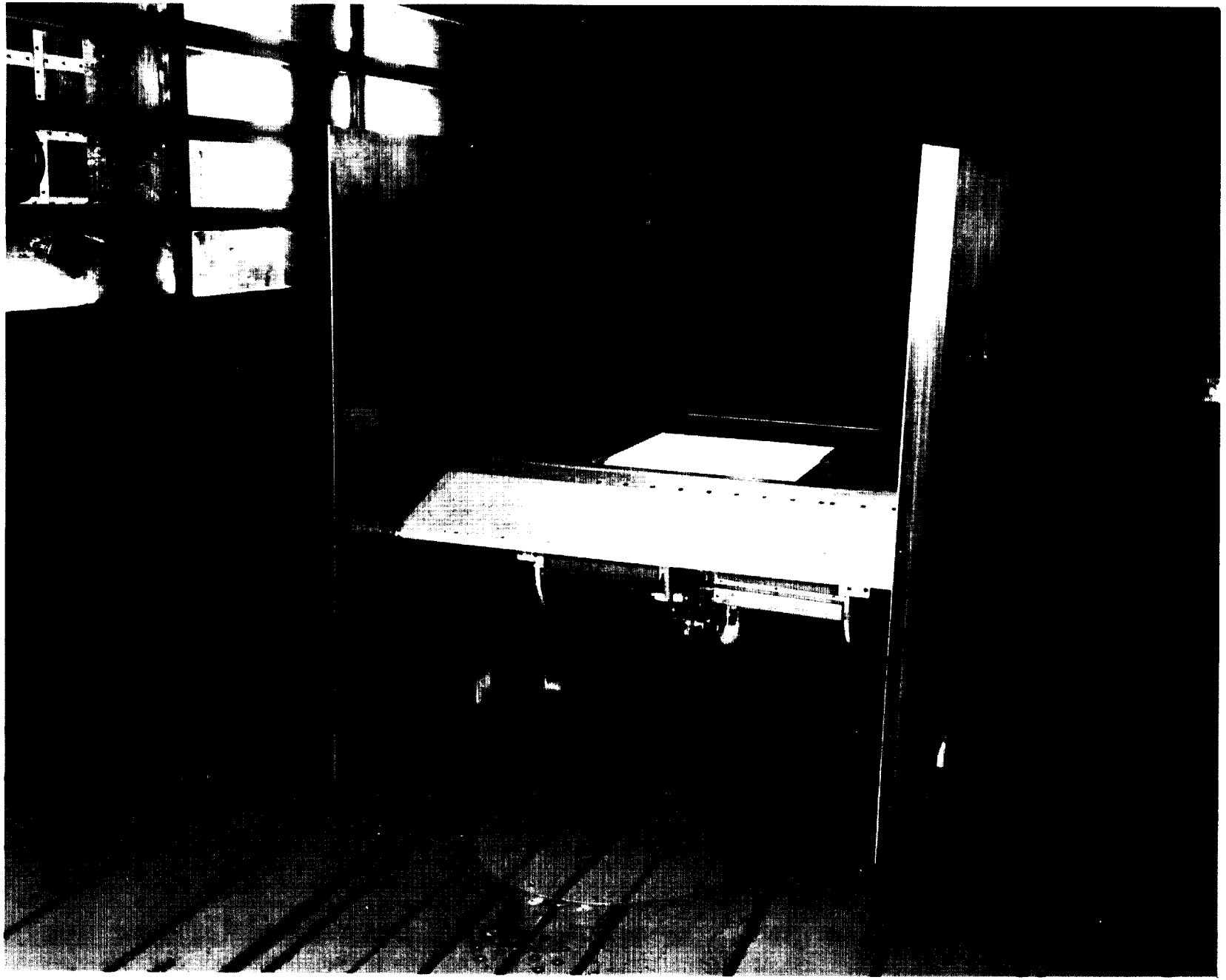
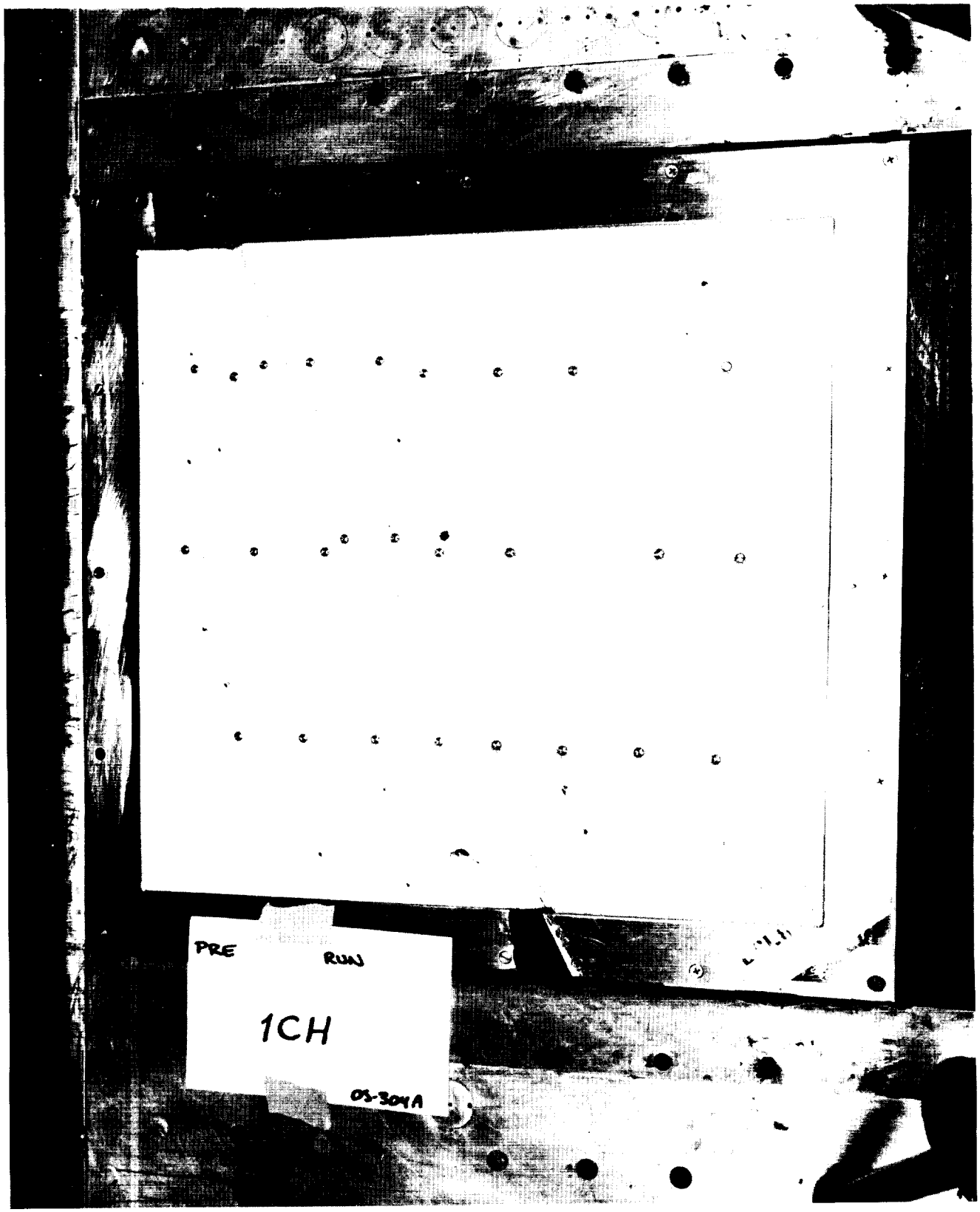
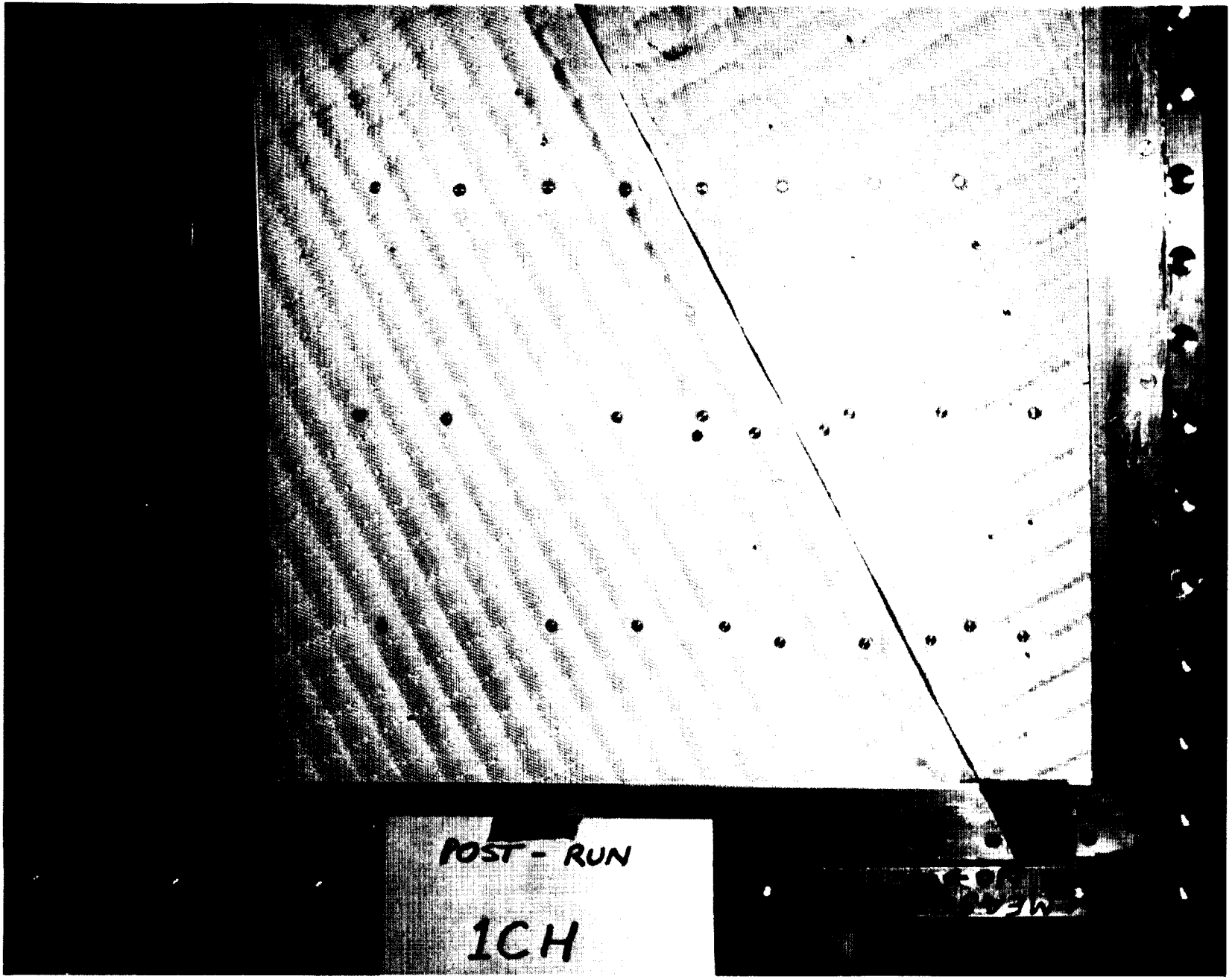


Figure 7
Installation Photograph

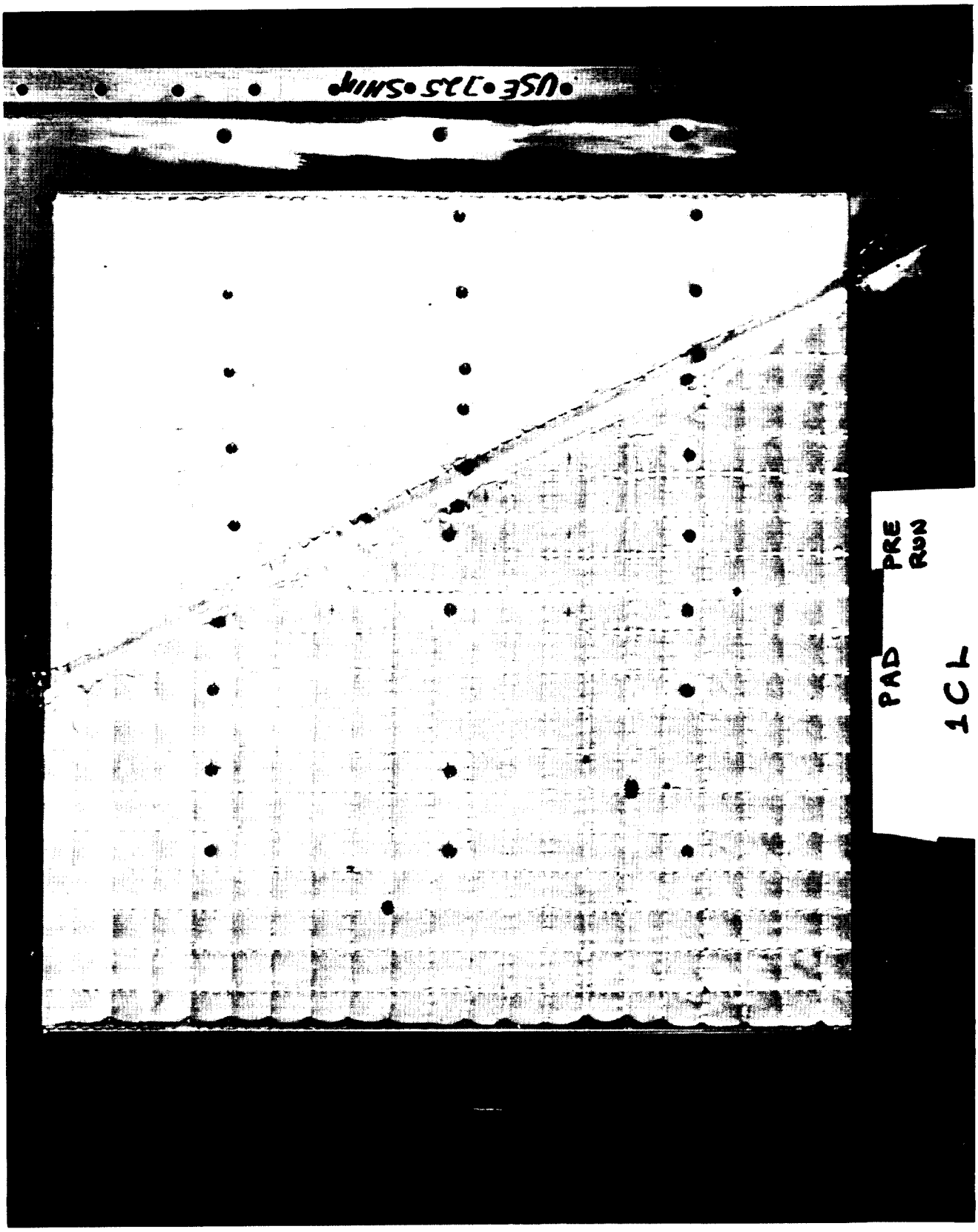


a. Specimen 1CH, Pre-Test

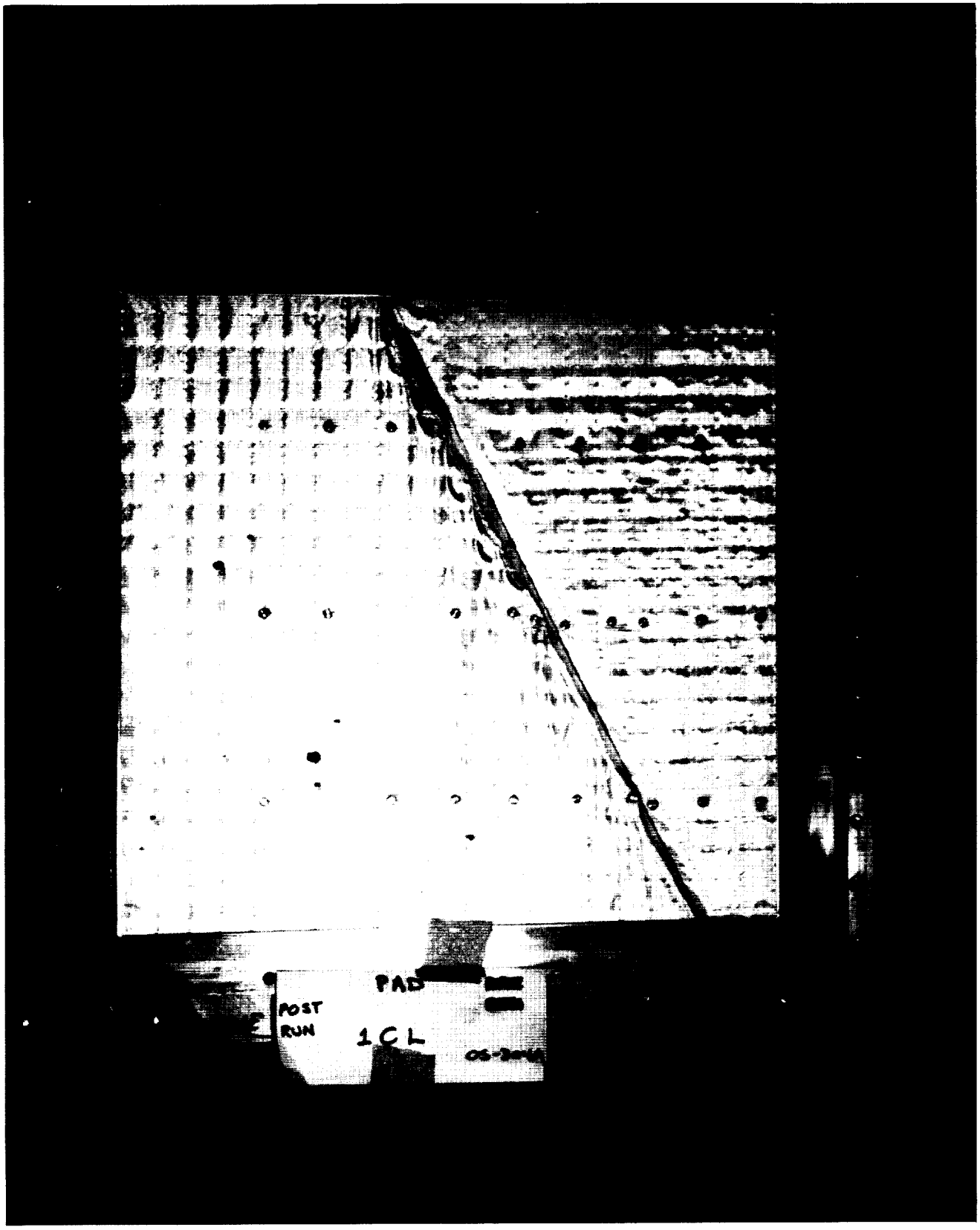
Figure 8. Pre-Test and Post-Test Photographs of AFRSI Specimens



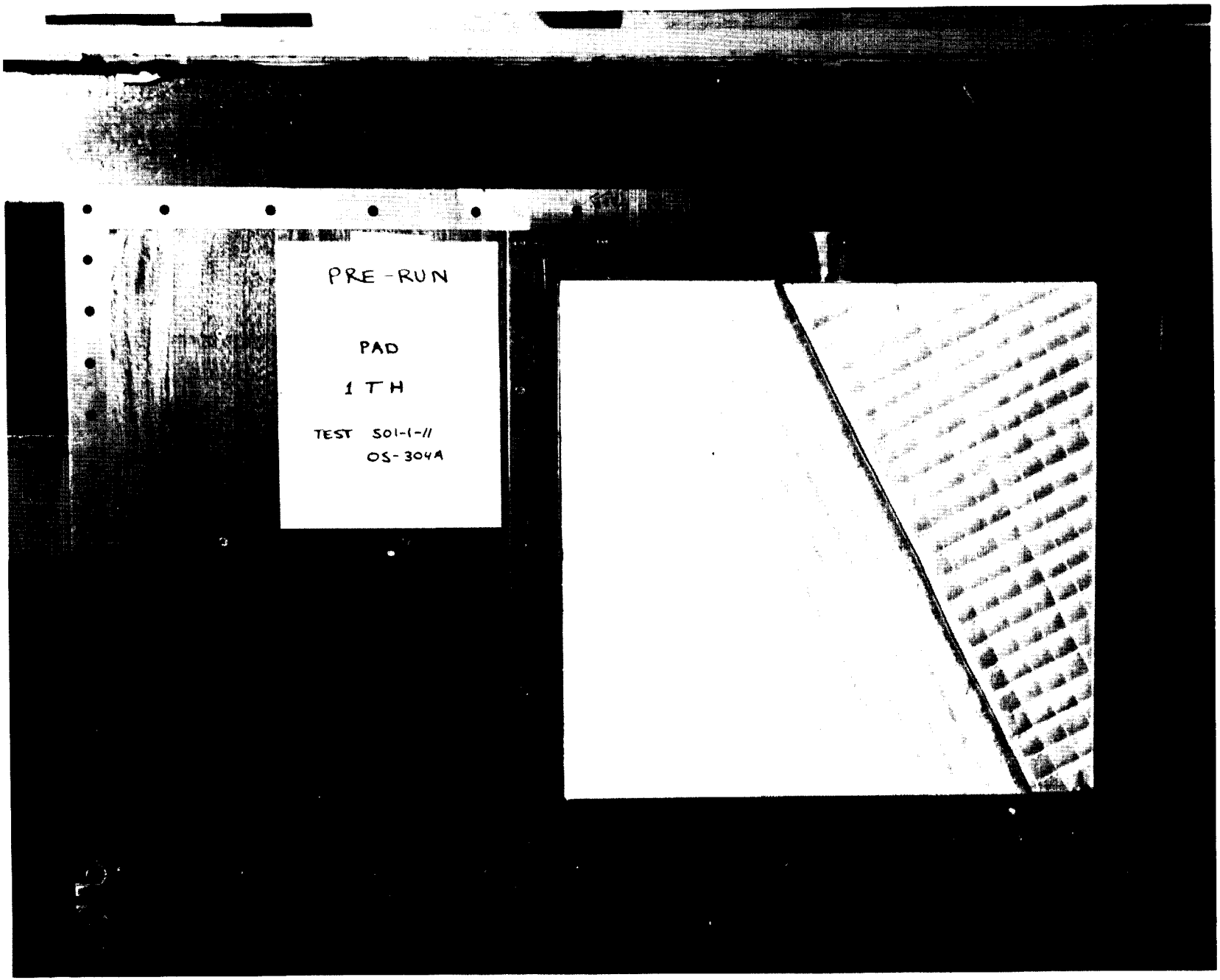
b. Specimen 1CH, Post-Test, Runs 31-34
Figure 8 (Continued)



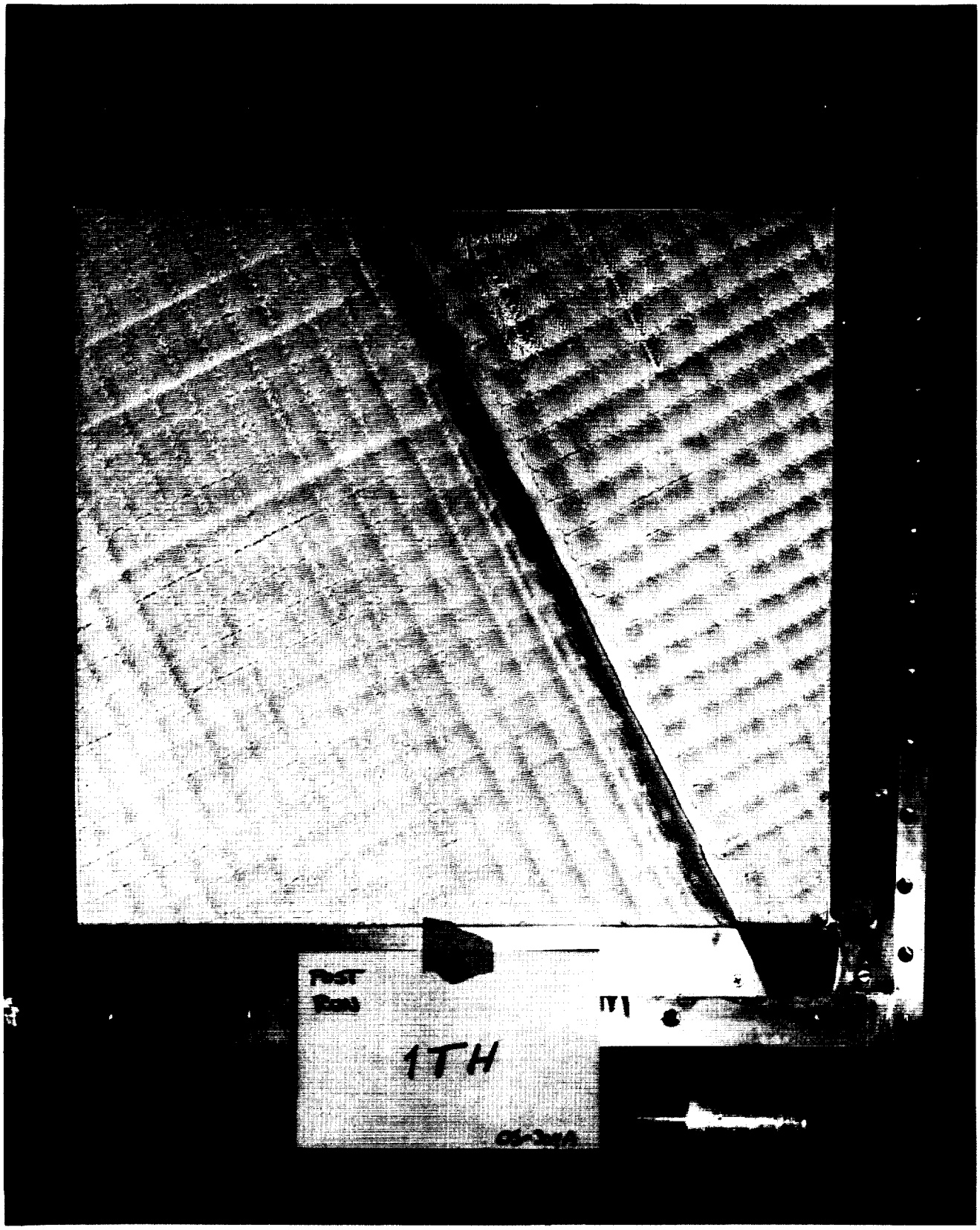
c. Specimen 1CL, Pre-Test
Figure 8 (Continued)



d. Specimen 1CL, Post-Test, Runs 7-12
Figure 8 (Continued)

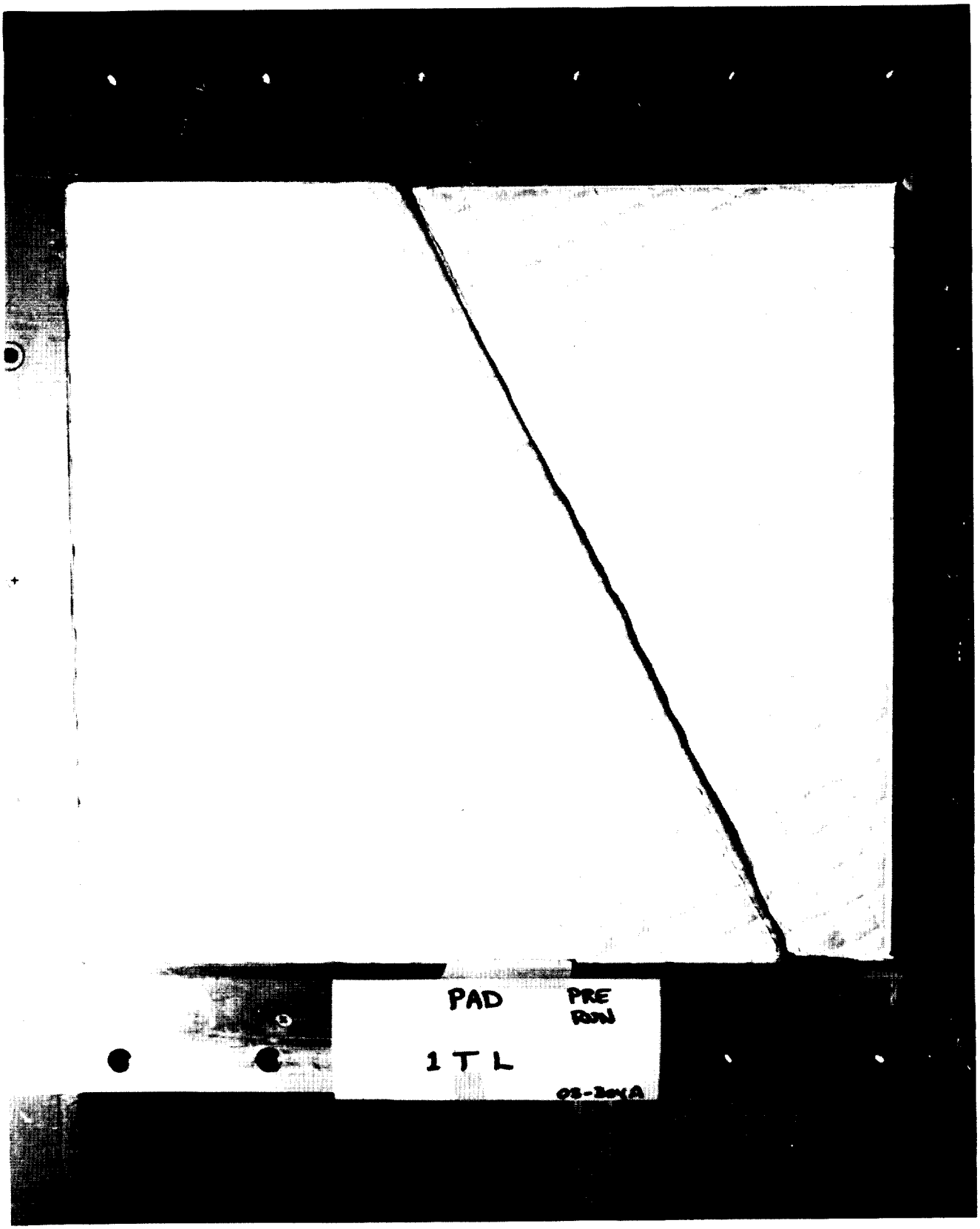


e. Specimen 1TH, Pre-Test
Figure 8 (Continued)



f. Specimen 1TH, Post-Test, Runs 14-23

Figure 8 (Continued)



g. Specimen 1TL, Pre-Test
Figure 8 (Concluded)

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